Direct Dark Matter Detection

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WIMP Direct Detection

Look for anomalous nuclear recoils in a low-background detector.

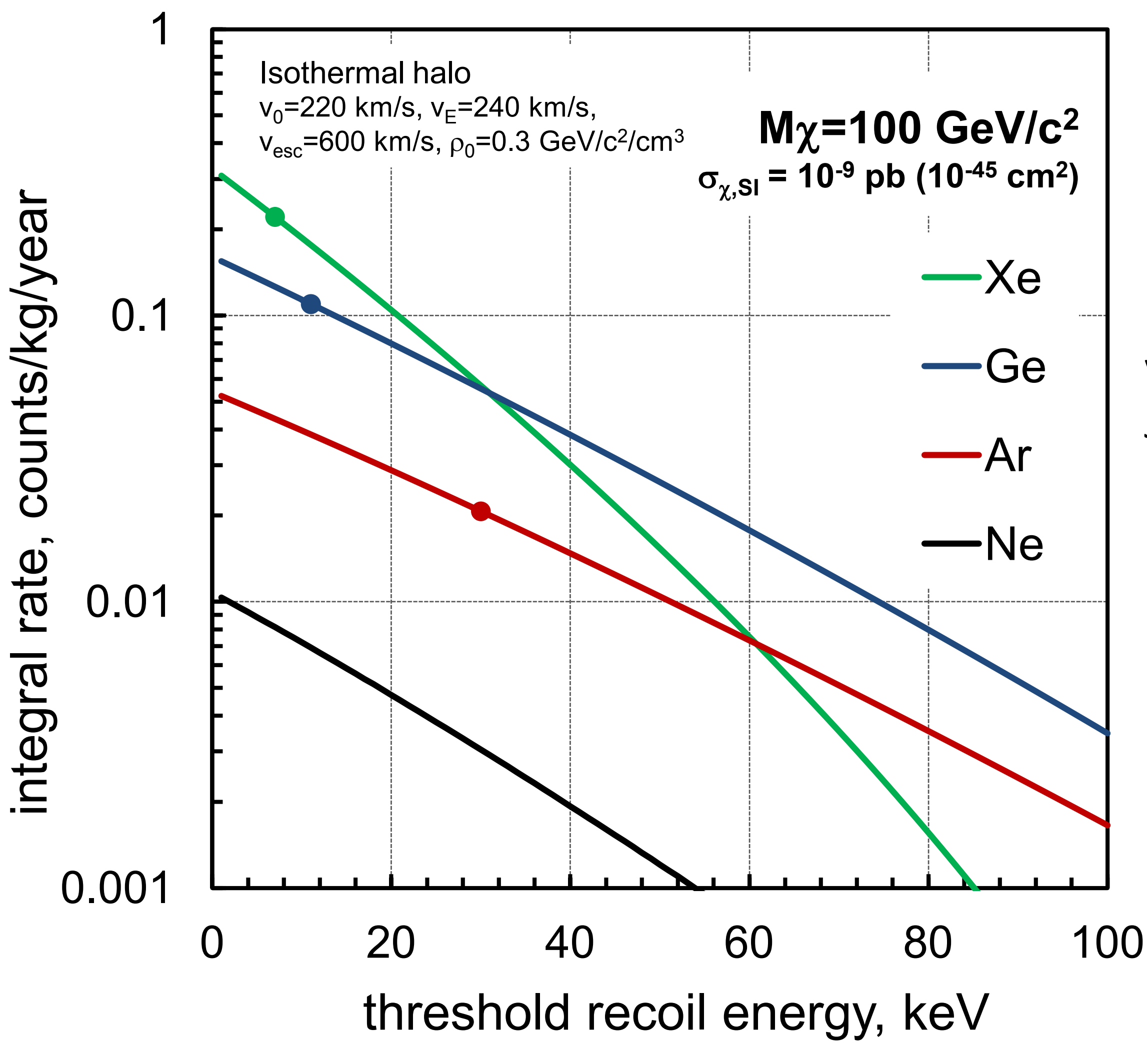
$R = N \rho \sigma \langle v \rangle$

From $\langle v \rangle$ = 220 km/s, get order of 10 keV deposited

Requirements:

- Low radioactivity
- Low energy threshold
- Gamma ray rejection
- Scalability

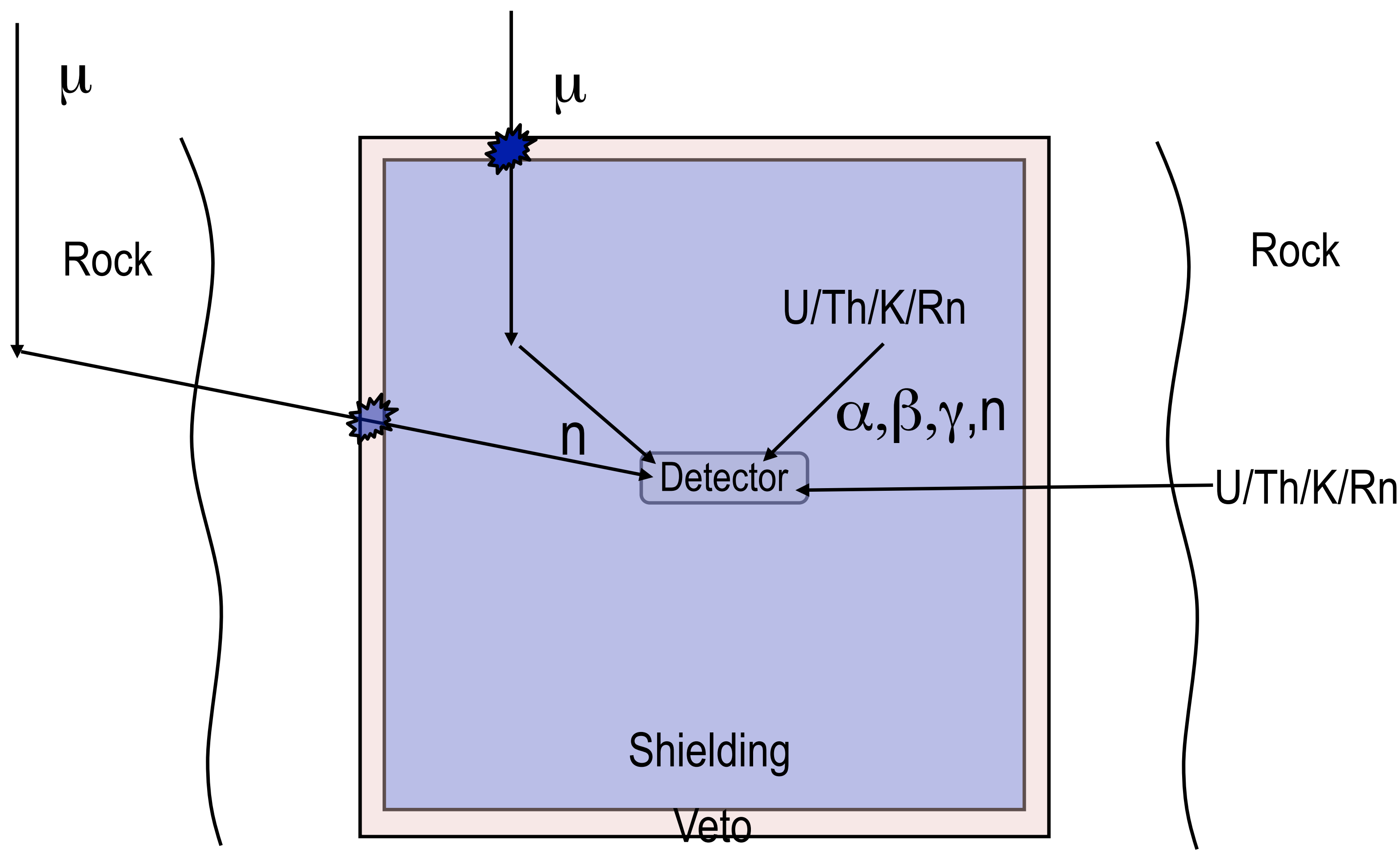
Predicted nuclear recoil spectra from WIMP-nucleus scattering



V. Chepel and H. Araujo, JINST 8, R04001 (2013).

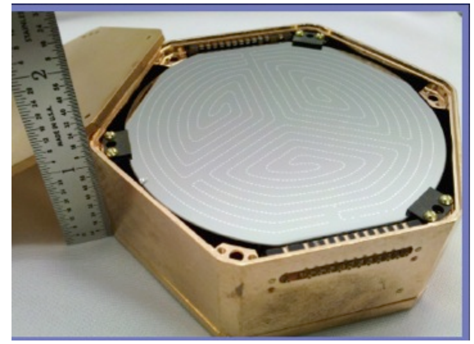
Background sources and shielding in a typical dark matter experiment.

Need sensitivity of better than 1 event/100kg/year

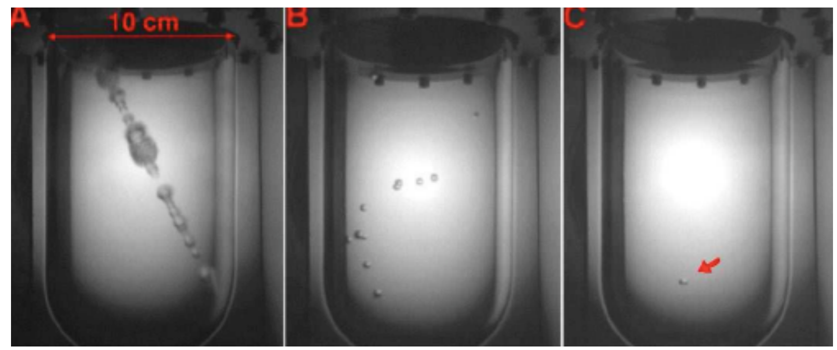


WIMP Direct Detection Technologies

- Cryogenic Ge detectors (CDMS, Edelweiss, CRESST): Excellent background rejection, low threshold and good energy resolution.



- Threshold detectors (COUPP, SIMPLE, PICASSO): Ultimate electron recoil rejection, inexpensive, easy to change target material for both SI and SD sensitivity.



- Single-phase LAr, LXe (DEAP, CLEAN, XMASS): Simple and relatively inexpensive per tonne, pulse-shape discrimination and self-shielding.

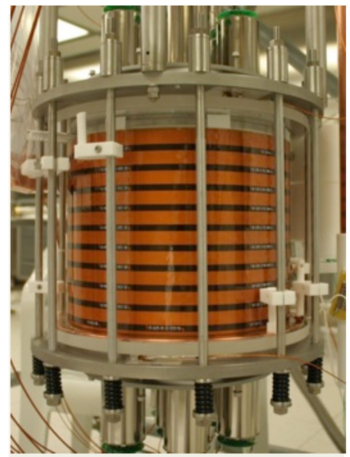
WIMP Direct Detection Technologies

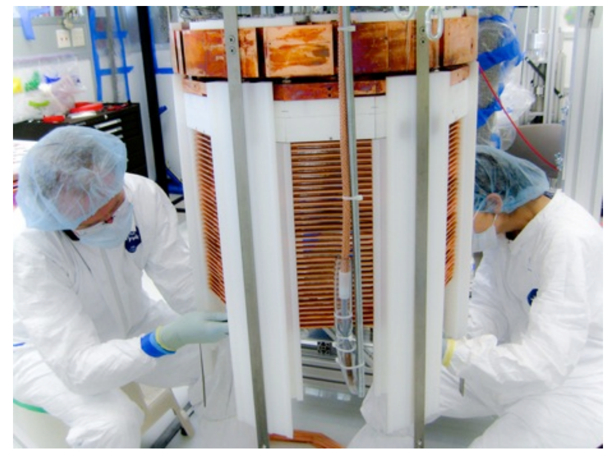
- Dual-phase Ar (DarkSide, ArDM):
  Excellent electron recoil rejection, position resolution.

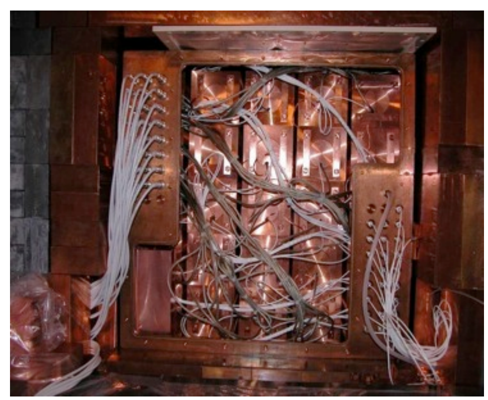
- Dual-phase Xe (XENON, LUX, Panda-X):
  Suitable target for both SI and SD, low energy threshold, excellent position resolution, self-shielding.

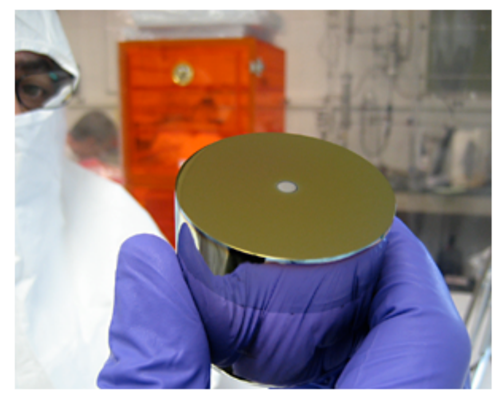
- Scintillating crystals (DAMA/LIBRA, KIMS):
  Annual modulation with large target mass.

- Ionization detectors (CoGeNT, DAMIC):
  Very low energy threshold, good energy resolution.

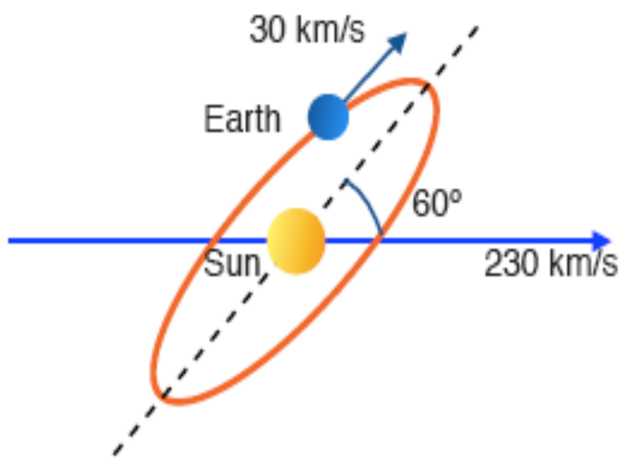


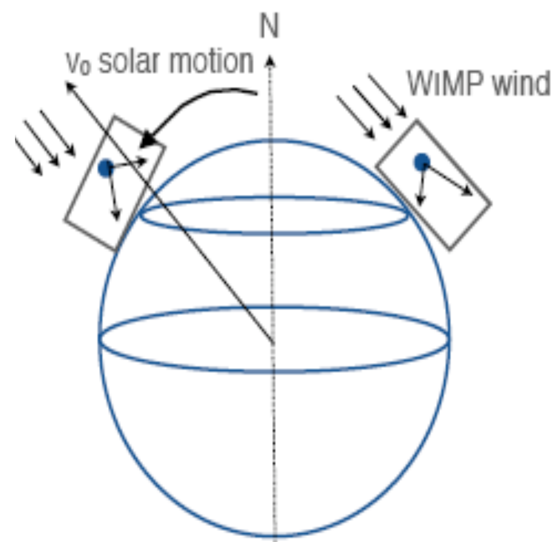


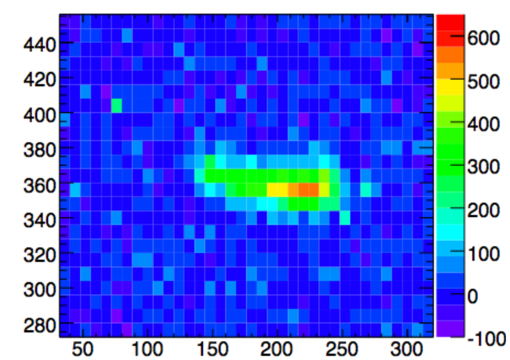




WIMP Directional Detectors
(DRIFT, DMTPC, D^3, MIMAC, NEWAGE, NEXT/Osprey)

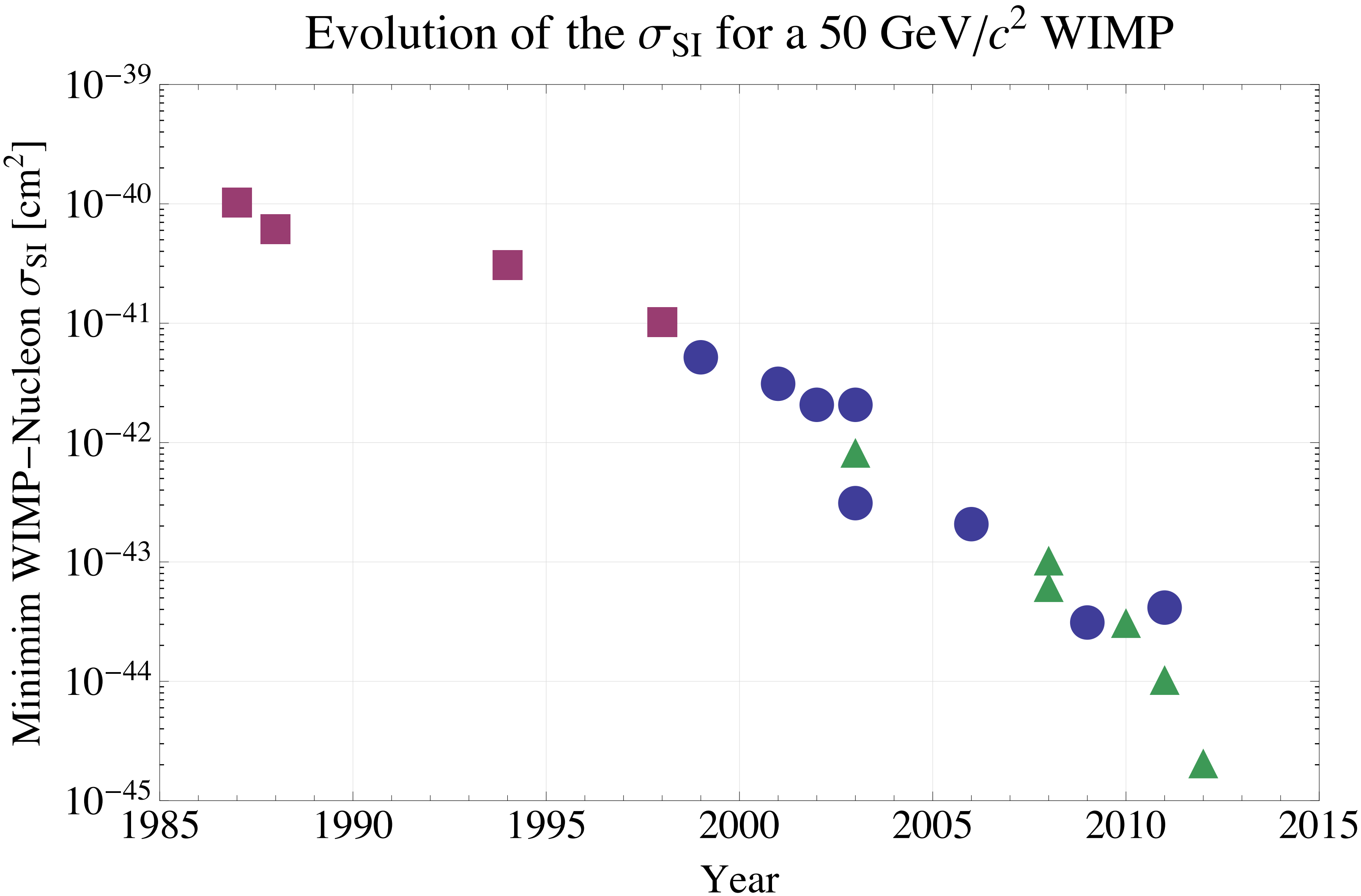




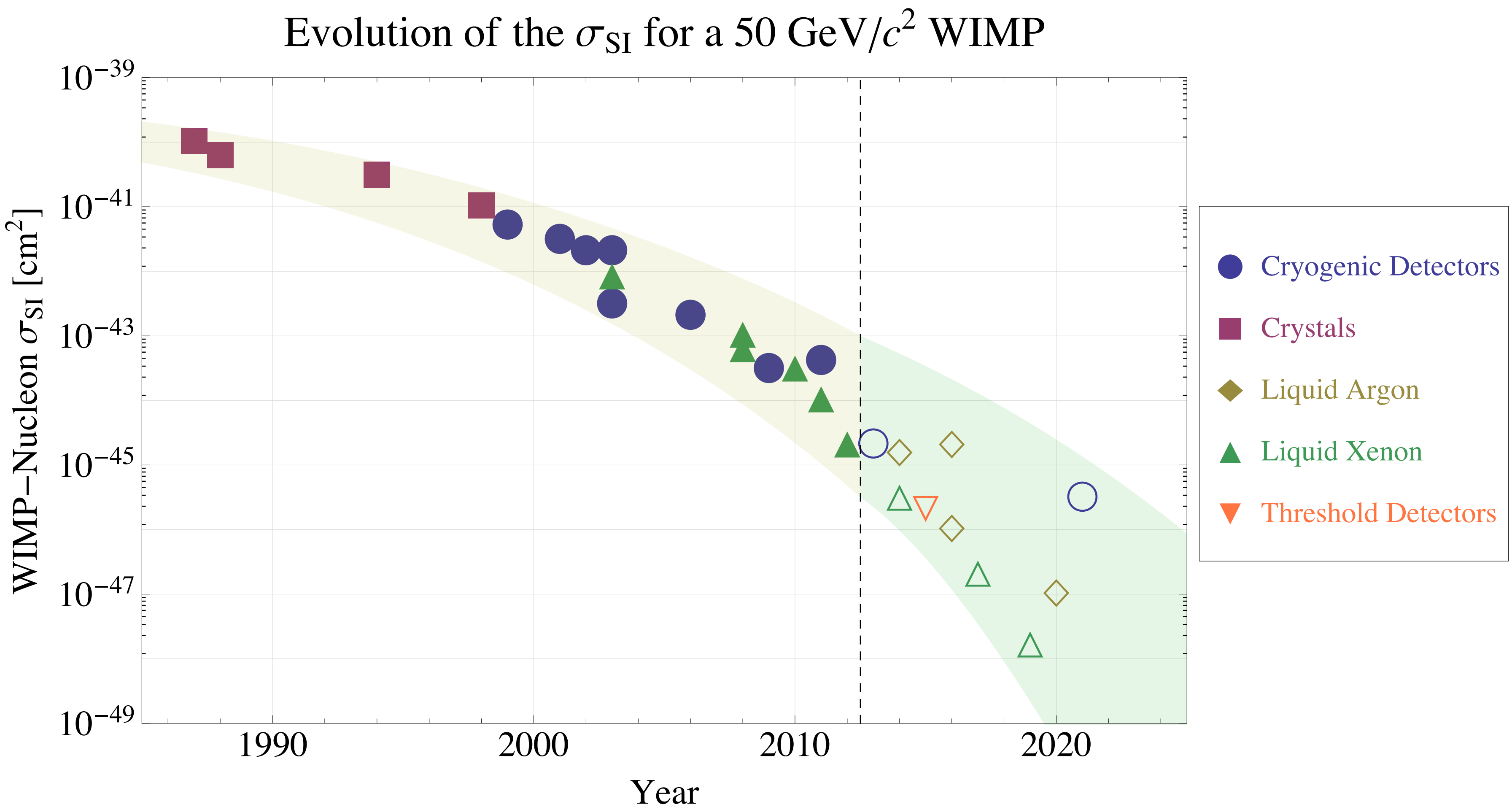


In the long run, directional detection will allow one to map out the velocity distribution of the dark matter in the galactic halo, and could serve as an important input to modeling of the detailed formation history and dynamics of the galaxy.

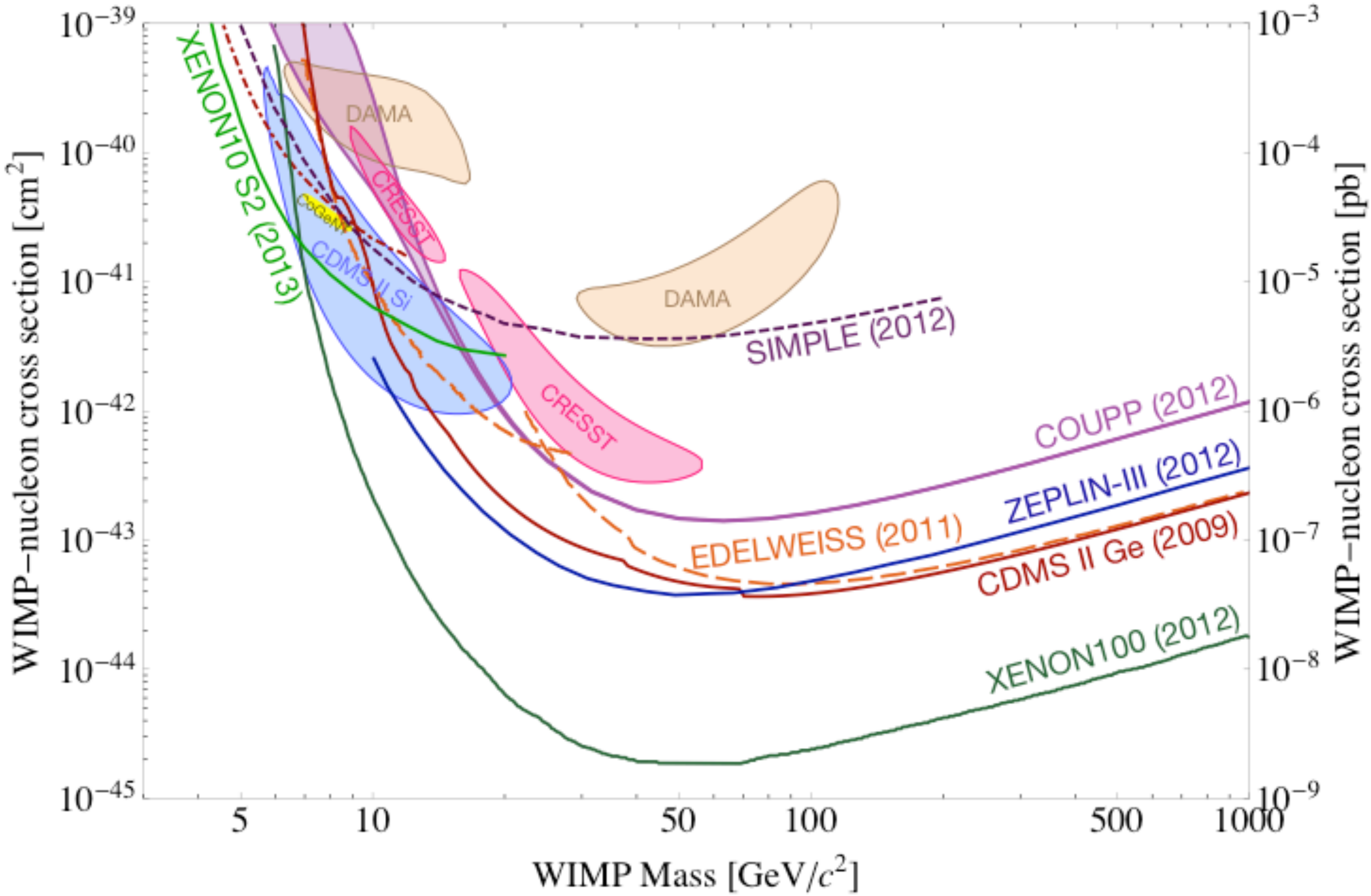
This field has seen tremendous progress over the past 25 years



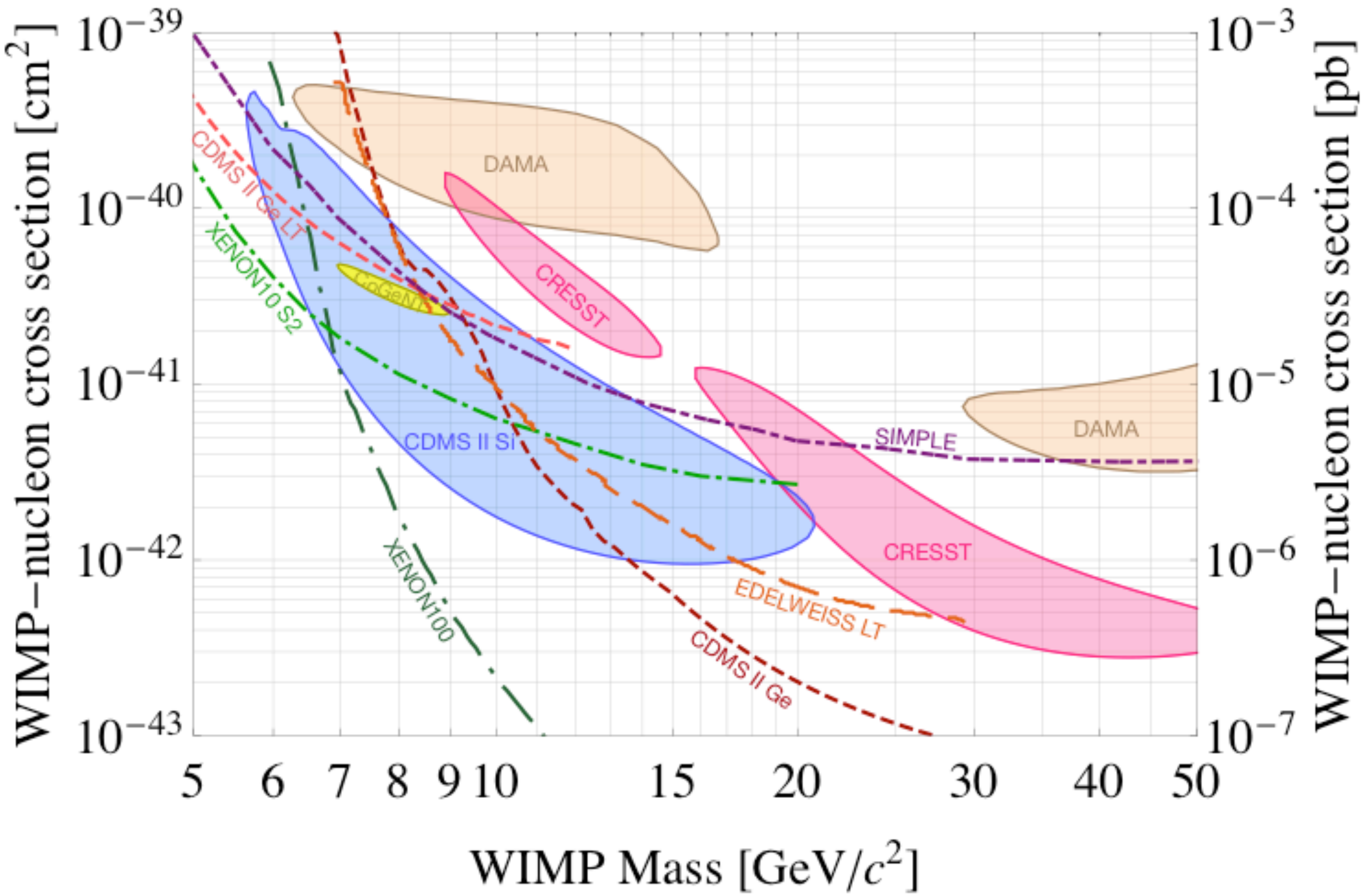
… and this progress is expected to continue.



Current limits

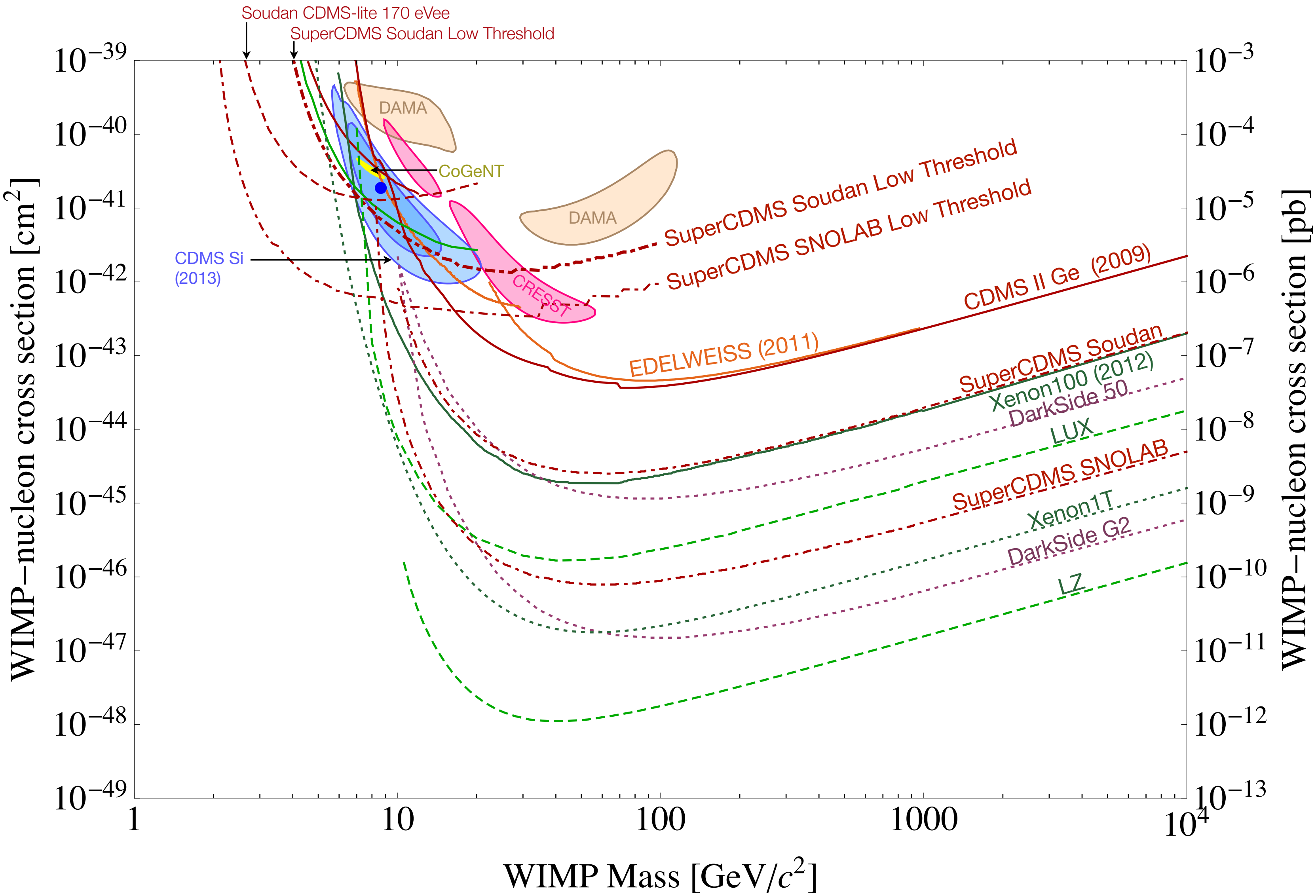


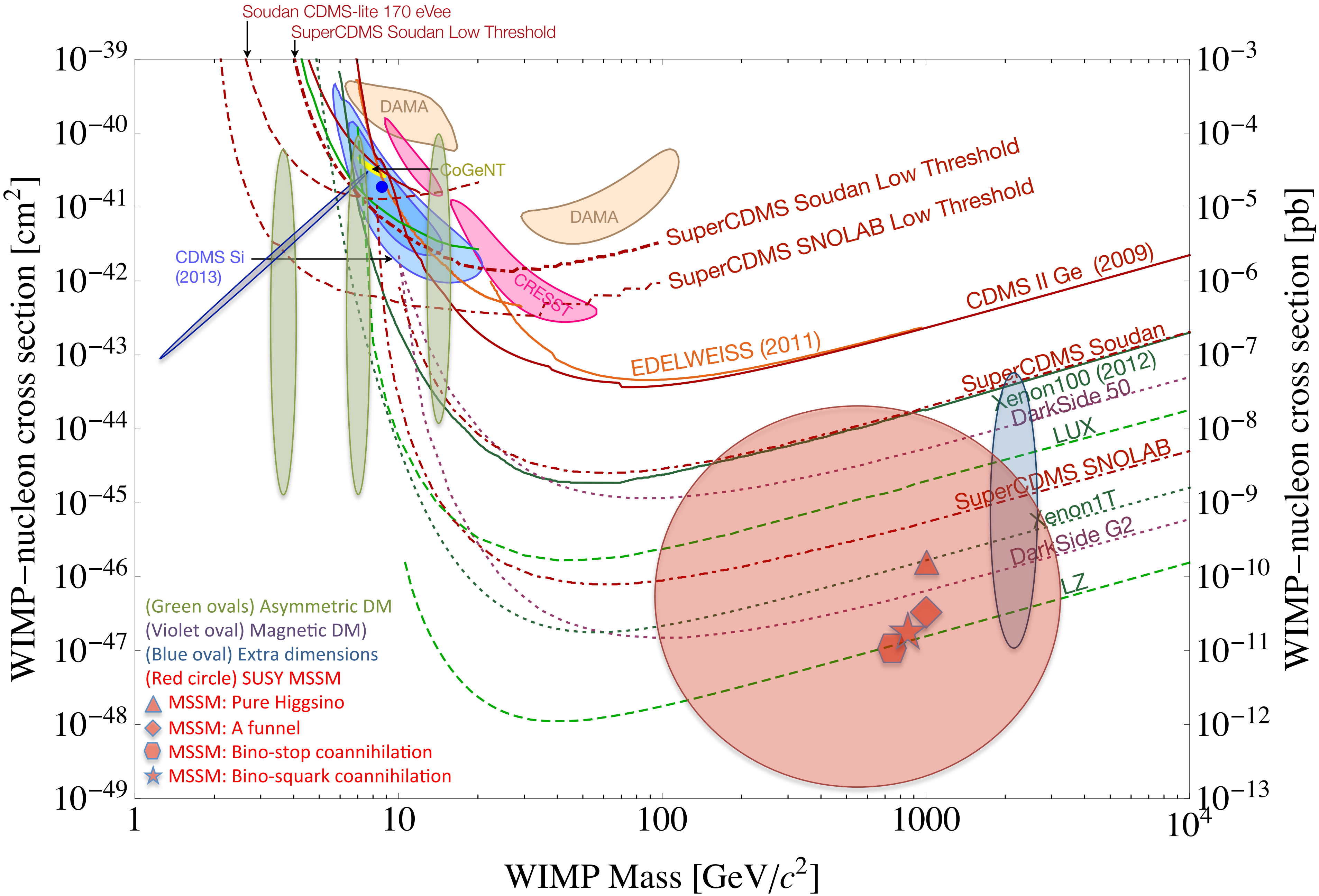
Low Mass WIMPs?



The resolution of these conflicts can only be achieved by observations with lower background, lower threshold, and higher discrimination detectors to either confirm or reject hints in the same target nuclei and then correlate with the magnitude of such signals in other targets. This will require improvement of existing detectors or development of new techniques.

Existing and projected spin-independent cross-section limits

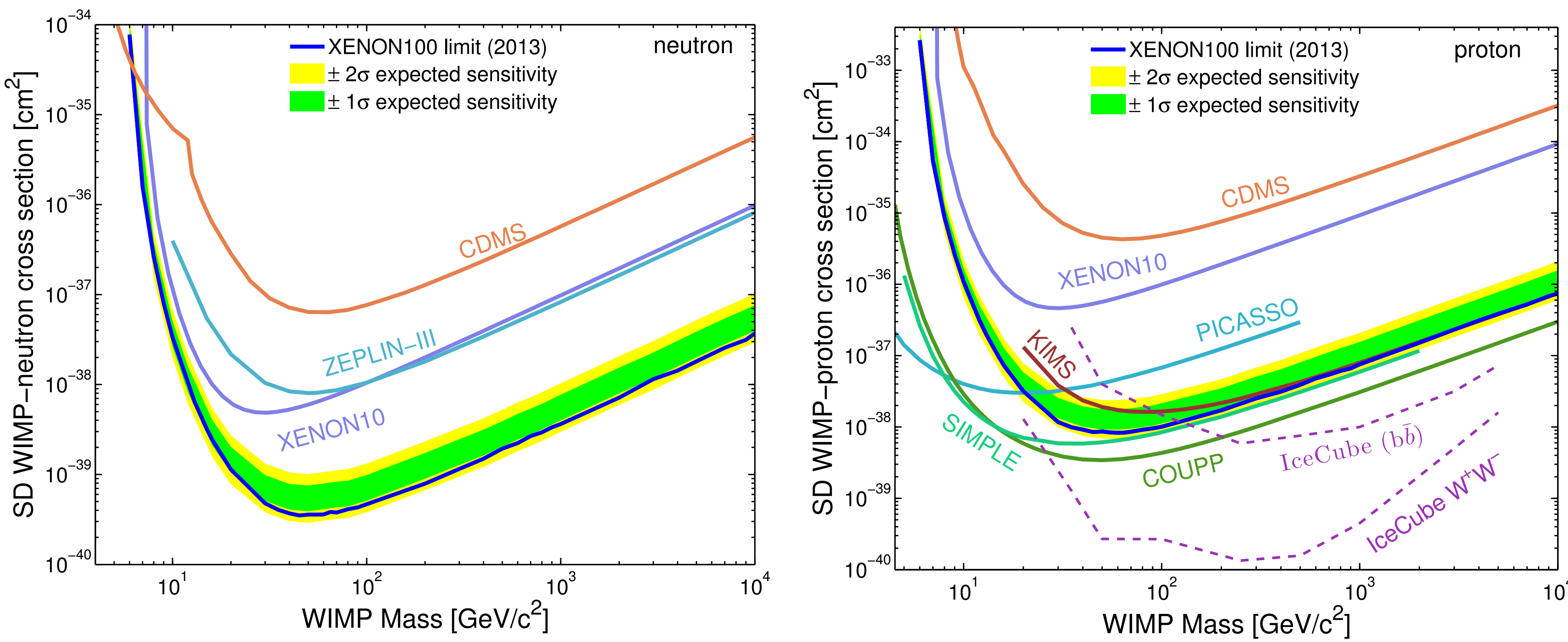




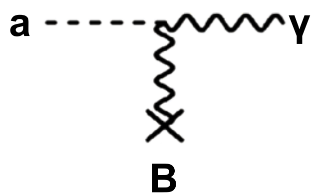
Soudan CDMS-lite 170 eVee
SuperCDMS Soudan Low Threshold
DAMA
DAMA
CoGeNT
CDMS Si
(2013)
CRESST
SuperCDMS Soudan Low Threshold
SuperCDMS SNOLAB Low Threshold
CDMS II Ge (2009)
EDELWEISS (2011)
SuperCDMS Soudan
Xenon100 (2012)
DarkSide 50
LUX
SuperCDMS SNOLAB
Xenon1T
DarkSide G2
LZ
(Green ovals) Asymmetric DM
(Violet oval) Magnetic DM)
(Blue oval) Extra dimensions
(Red circle) SUSY MSSM
MSSM: Pure Higgsino
MSSM: A funnel
MSSM: Bino-stop coannihilation
MSSM: Bino-squark coannihilation
WIMP–nucleon cross section [cm²]
WIMP–nucleon cross section [pb]
WIMP Mass [GeV/c²]

Spin-dependent cross-section limits

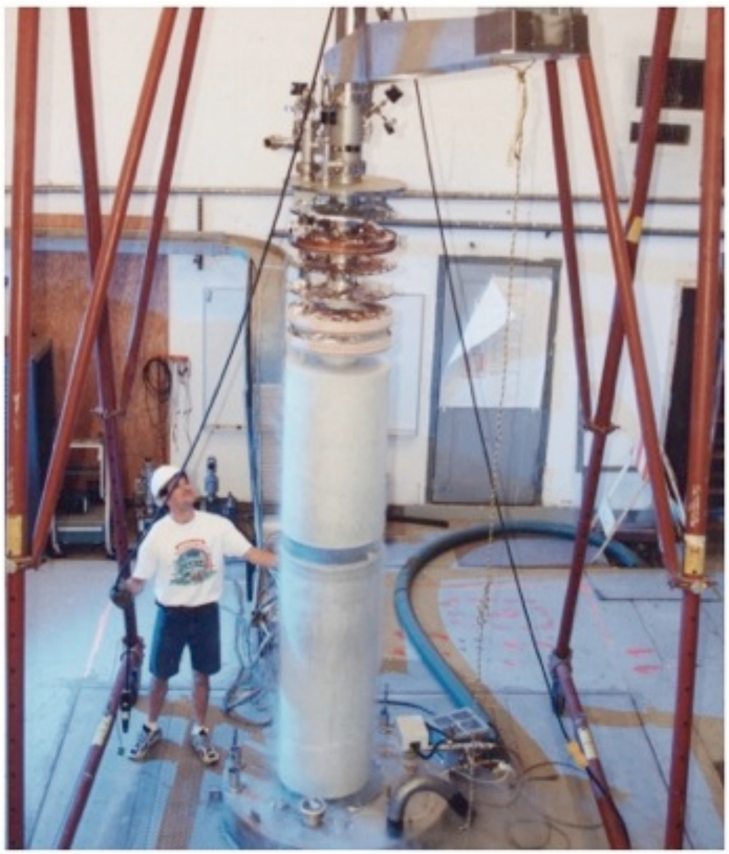
In spin-dependent coupling, the WIMP interacts with the free spin of the target, typically Parameterized as a neutron- or proton-spin dependent cross-section.

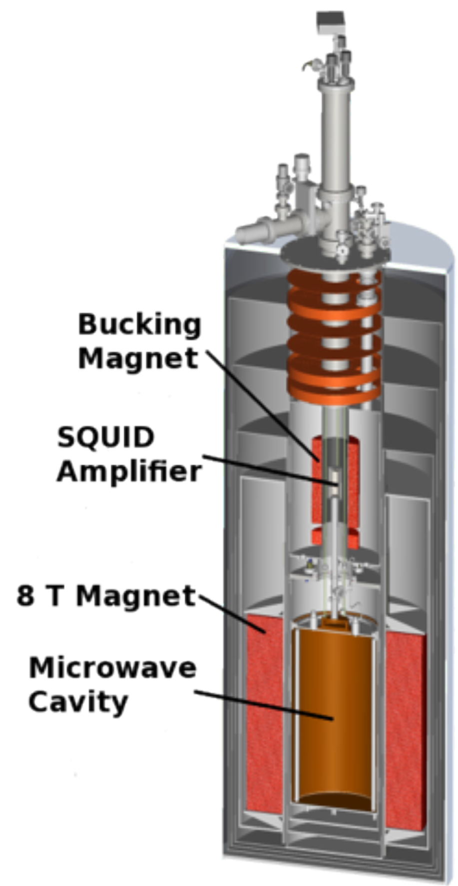


Axion Detection

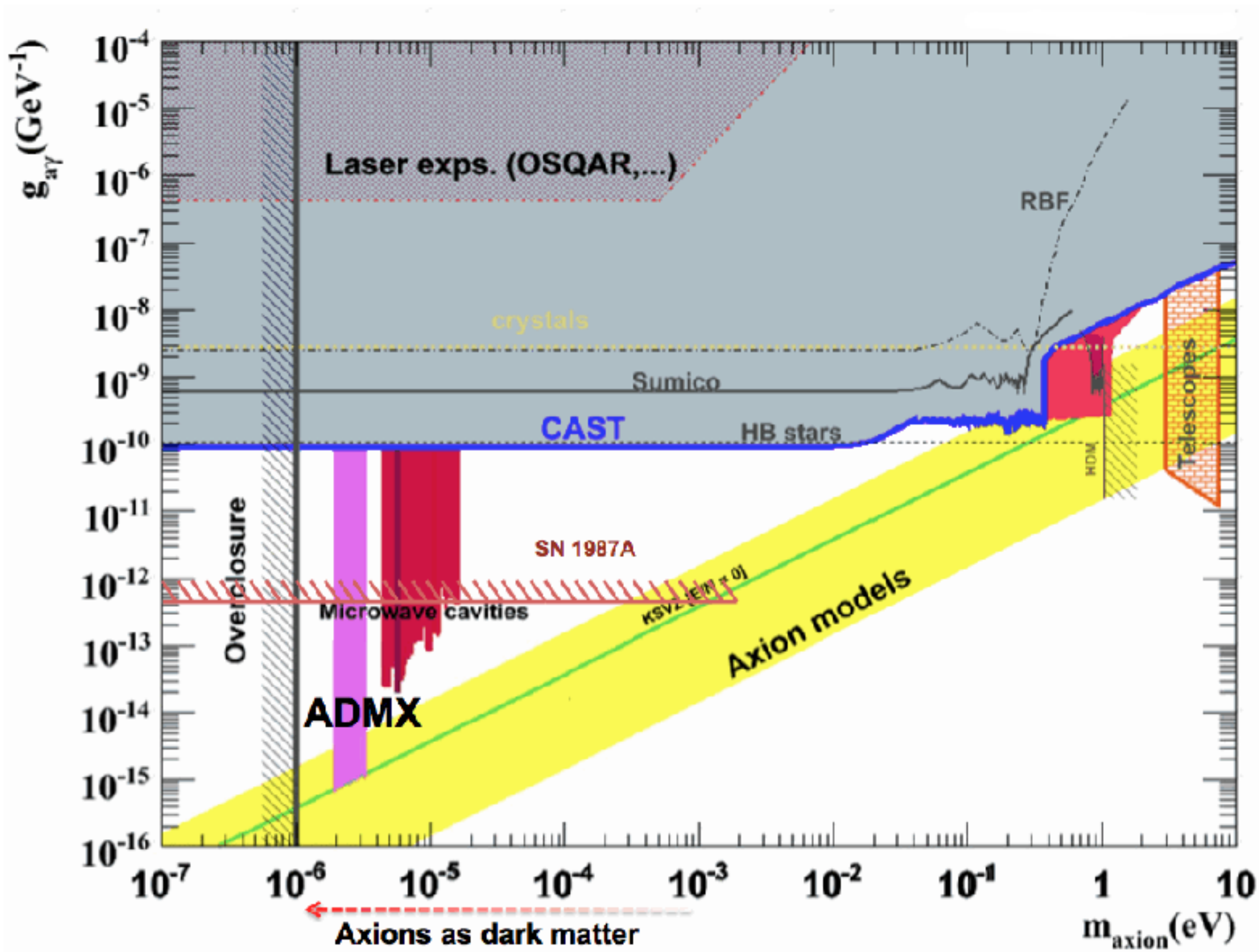


Dark matter axions may be converted into photons in a high magnetic field. ADMX (a resonant cavity axion detector) is sensitive to axions in the mass range 1 μeV to 100 μeV. Ongoing R&D to push to higher mass (higher frequency cavities)





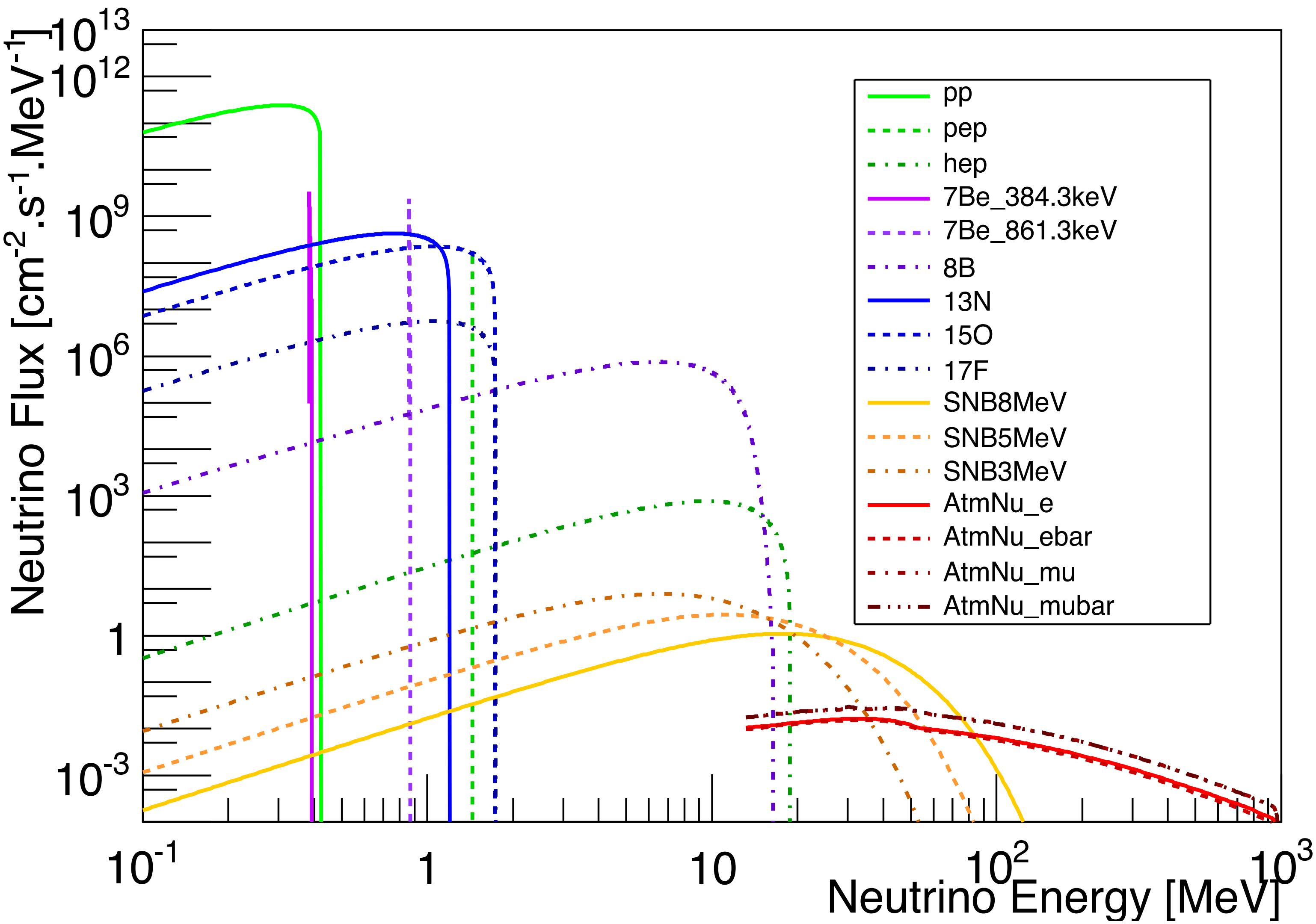
Axion detection: existing limits and future projections



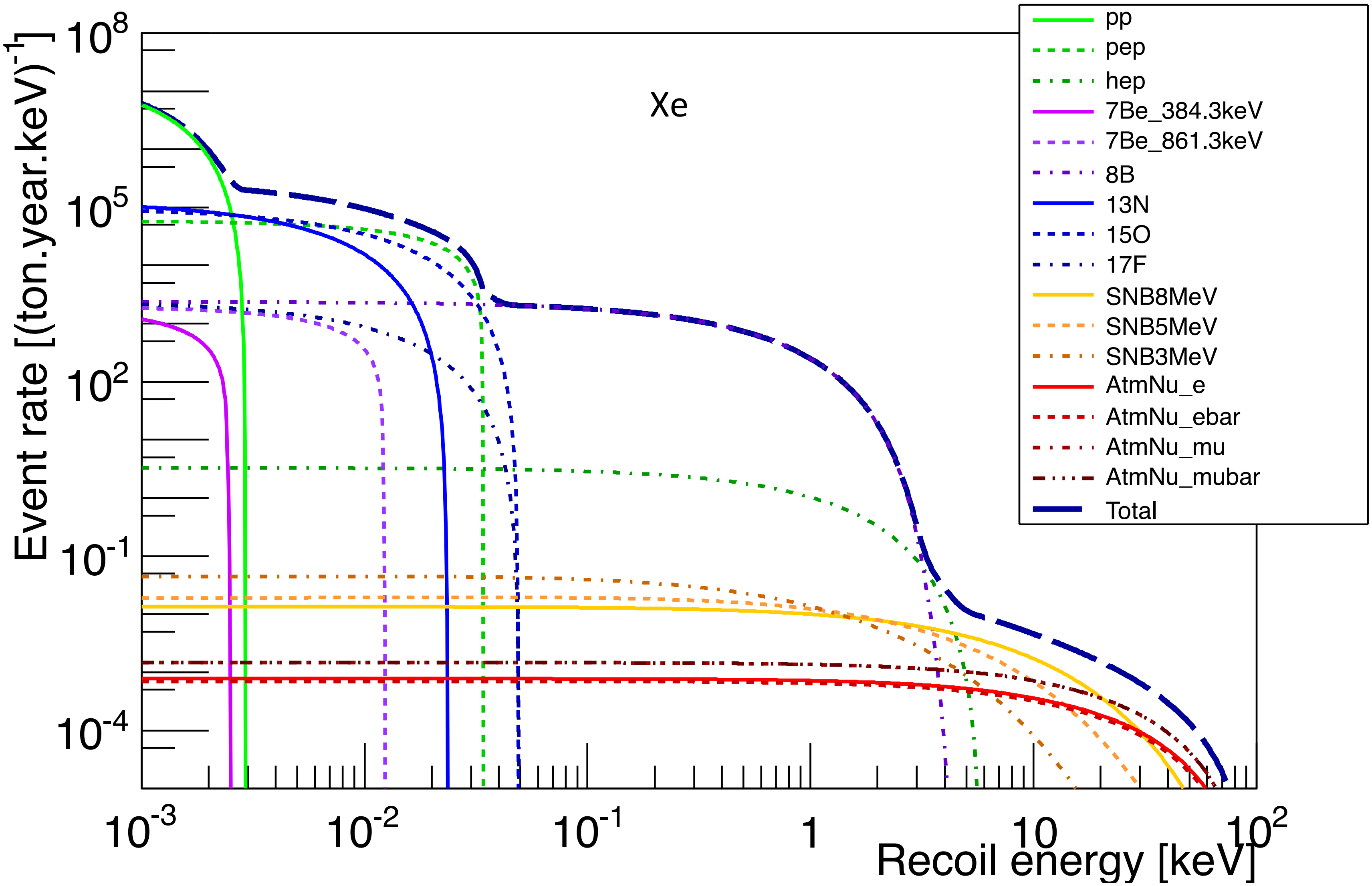
CF3. For direct detection, when is the right time to move from small projects toward larger ones?

Any new project should either be testing a putative WIMP signal, or have substantially better (~order of magnitude) sensitivity to WIMP-nucleon cross-section in some mass range. With high-mass WIMP sensitivities continuing to improve rapidly from one year to the next, it simply isn't possible to stay competitive without scaling up in target mass. The programmatic move from smaller to larger projects in the US is already part of DOE and NSF strategy, starting with the selection of a subset of so-called "Second Generation" dark matter detectors, and looking forward to worldwide collaboration on a few large scale "Third Generation" installations. On the other hand, if a putative WIMP signal is seen (such as the current indications at 8.6 GeV), then it can make sense to test the signal with several approaches, involving multiple targets and technologies. In this case there is less emphasis on scaling to a few large projects, and more emphasis on multiple, smaller experiments to test the signal.

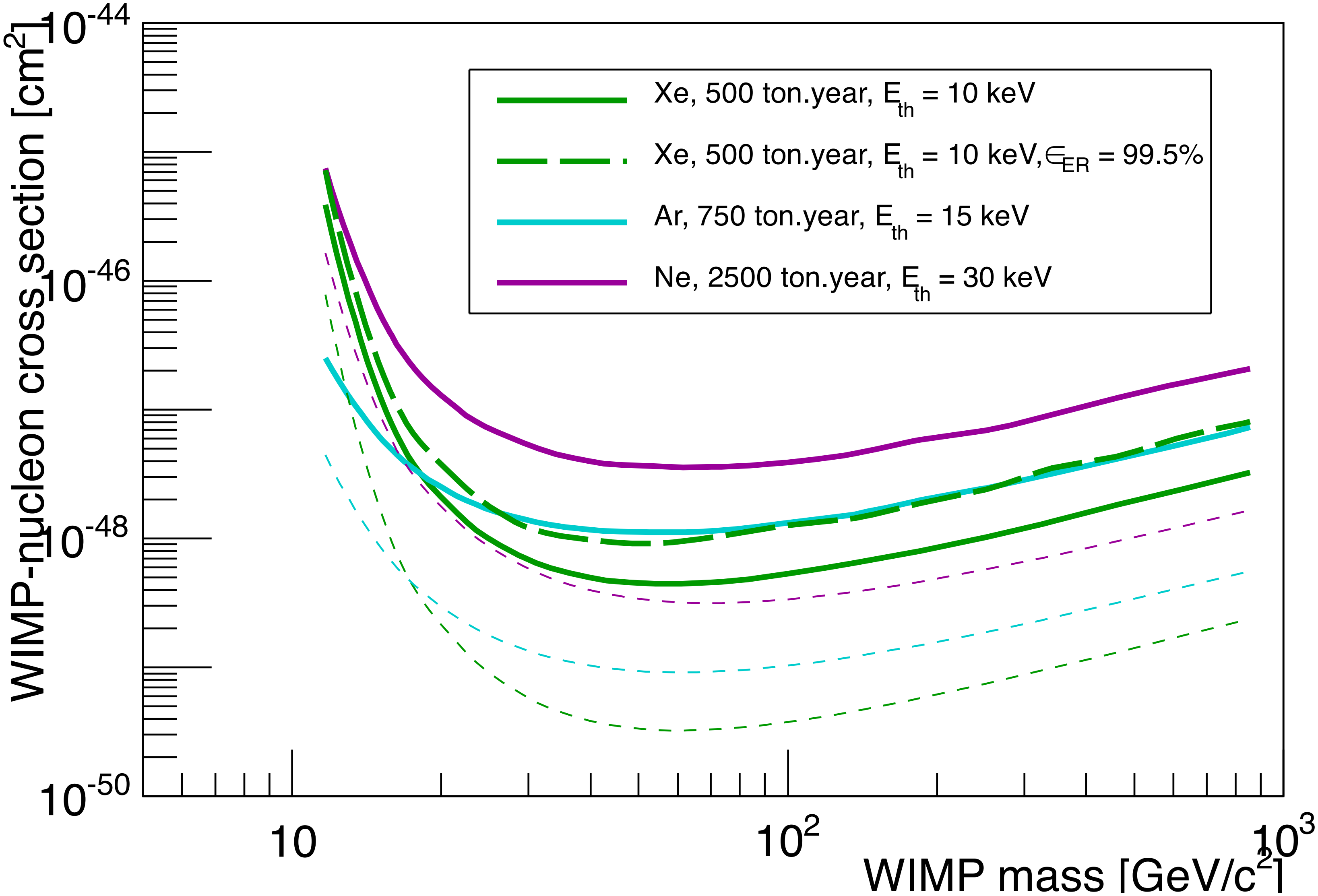
Solar and atmospheric neutrino fluxes



Coherent neutrino-nucleus scattering events
(Billard, Strigari, and Figeroa-Feliciano, arXiv:1307.5458)



WIMP sensitivity limits, given coherent neutrino scattering background (Billard, Strigari, and Figeroa-Feliciano, arXiv:1307.5458)



CF4. Dark matter direct detection will reach the neutrino background at some stage. Although this background is not formally irreducible, is it realistic to think that one could go beyond this? What experiments would make this possible in a cost-effective way?

Achieving sensitivities below the neutrino floor will require extremely large detectors capable of disentangling the small energy dependence of neutrino and WIMP-induced signal. In this case, maintaining stable operation to be sensitive to annual modulation can provide an additional constraint. Better understanding of solar and atmospheric neutrino physics can narrow down the neutrino spectrum normalization and aid in background subtraction. Detectors with directional capability and head-tail discrimination can also push beyond the neutrino floor, provided they are very large, of mass 10 tons and above.

CF5. To what level should we continue to search directly for WIMP dark matter in the absence of a convincing signal? Is there a technique, or a motivation, to search beyond the neutrino floor? Is there a natural stopping point for direct DM searches?

The neutrino floor may be a natural stopping point if the cost of detectors with masses in the tens of tons is prohibitively high or if a path to comparable size directional detector technology cannot be demonstrated. However, from the theory side, there are compelling models that predict a variety of dark matter masses with small cross-sections, motivating continued exploration of WIMP cross-sections beyond the neutrino floor, across a wide range of WIMP masses.